A State of the Environment Fact Sheet

Ground-level ozone in Canada

The ozone problem at the Earth's surface is accumulation rather than depletion

From a distance, many of the world's large cities appear to be enveloped in a brownish-yellow haze, known as smog. Smog is a mixture of air pollutants, including vapours, gases, and particulates. During the spring and summer months in Canada a major component of this smog is ozone, a colourless and irritant gas. Today in some cities, concentrations of ozone periodically reach levels high enough to affect the health of people and vegetation and to corrode materials such as rubber tires and fabrics. In addition, air masses transport the smog, including the ground-level ozone pollution, far downwind. Excess ozone that reaches rural areas damages and slows the growth of farmers' crops, inhibits the growth of trees, and may even be contributing to a decline in forest health in parts of eastern Canada.

The country's ground-level ozone problem is particularly serious in parts of B.C., Ontario and Quebec, and the Maritimes. The Canadian Council of Ministers of the Environment (CCME) has identified three ozone problem areas: the Lower Fraser Valley, the Windsor–Quebec Corridor, and the Southern Atlantic Region. The federal government's Ground-level Ozone Indicator, which is one of a national set of environmental quality measures, shows that the maximum acceptable ozone objective is often exceeded in these areas.

Edward W. Manning

Urban smog

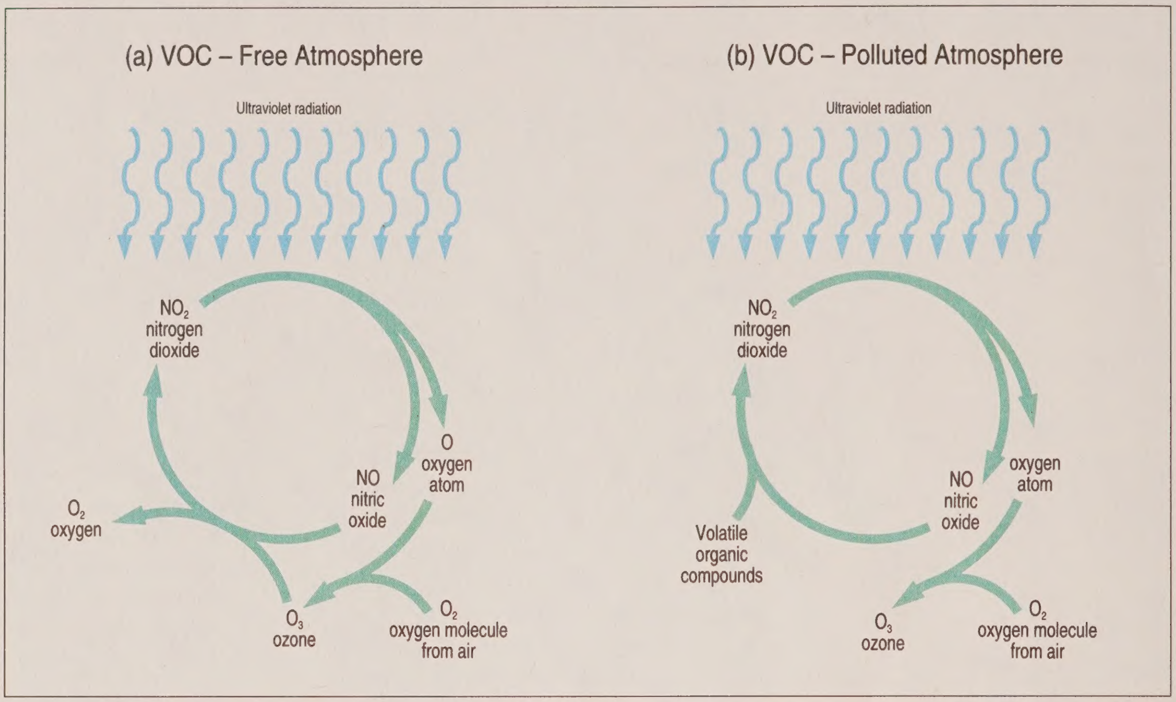
Ozone: two types of problems

It is important not to confuse the problem of ground-level ozone pollution with the thinning of the stratospheric ozone layer. About 90% of atmospheric ozone occurs in the stratosphere, a layer that extends from about 15 to 50 km above the Earth's surface. There it performs the critical function of absorbing harmful ultraviolet (UV) radiation emitted by the sun. At present the stratospheric ozone is thinning and providing plants and animals with less protection from the harmful effects of excess UV radiation than in the past. This is an urgent problem; however, it is not the topic of the fact sheet.

The ozone problem at the Earth's surface is accumulation rather than depletion. The normal state of affairs at ground level is for ozone to form and almost immediately break down, at the same rate at which it is being produced, by releasing one oxygen atom. Figure 1a shows the chemical cycle involving oxygen (O_2) and two of the nitrogen oxides (NO_x) (in this case, nitric oxide and nitrogen dioxide), sunlight, and high temperatures that governs the formation and breakdown of ground-level ozone. Problems arise when volatile organic compounds (VOCs) (see "Chemical precursors of ground-level ozone" for a description of VOCs) are added to the mix (Figure 1b).

Because the buildup of ozone at ground level depends upon the concentration of other pollutants, as well as temperature and sunlight, ozone levels usually peak in the late afternoon of hot summer days and can persist into the evening and night.

Figure 1
In unpolluted air, ground-level ozone forms and breaks down in a steady cycle. Scenario b shows one way that pollutants disrupt the natural equilibrium.



Source: Hilborn and Still (1990).

Just how much ozone builds up varies considerably from year to year and from region to region, but summers that are hotter than normal generally produce more episodes of ozone pollution.

Ozone is a secondary pollutant in that it is not emitted directly to the atmosphere.

Chemical precursors of ground-level ozone

Ozone is a secondary pollutant in that it is not emitted directly to the atmosphere. Nitrogen oxides and VOCs, both of which are emitted by natural processes and human activities, are called ozone precursors because they must be present for ozone to form (Figure 1).

Nitrogen oxides

This group of nitrogen–oxygen compounds includes the gases nitric oxide, nitrogen dioxide, and nitrous oxide. Natural sources of nitrogen oxides are forest fires, lightning, and bacterial action in the soil. About 95% of human-caused emissions of nitrogen oxides come from the combustion of gasoline, diesel fuel, heavy fuel oil, natural gas, coal, and other fuels, notably in motor vehicles, heavy equipment, turbines, industrial boilers, and power plants (Figure 2).

Volatile organic compounds (VOCs)

The term "volatile organic compounds" is used to describe carbon-containing gases and vapours that are present in the air, with the major exceptions of carbon dioxide, carbon monoxide, methane, and chlorofluorocarbons (CCME 1990). VOCs are given off by trees and other vegetation, particularly in heavily forested areas. The combustion of fossil fuels, especially in cars and trucks; certain industrial processes; and the evaporation of some liquid fuels and solvents found in cleaning solvents, oil-based paints, varnishes, stains, and thinners are important sources of human-caused VOCs (Figure 3). Releases of VOCs lead to ground-level ozone pollution when these emissions occur in the presence of nitrogen oxides (Figure 1).

Effects of ground-level ozone

Effects on human health

Ozone is a very irritating and harmful gas. It adversely affected lung function in young, normal subjects who exercised for 6 hours in concentrations as low as the present Canadian 1-hour objective of 82 parts per billion (ppb) (Horstman *et al.* 1990). (A part per billion is a unit of measure used to describe the concentration of atmospheric gases. In this case, the unit represents one molecule of ozone in one billion molecules of all gases in the air.) When lung function is affected, ozone has probably caused inflammation in the lung.

Scientific studies show that after a few days of continuous exposure to ozone, respiratory discomfort disappears. However, although little is known of the long-term effects of repeated ozone exposure on humans, recent research on animals suggests that it may lead to irreversible changes in lung function (Tepper *et al.* 1987, cited in Lippmann 1989).

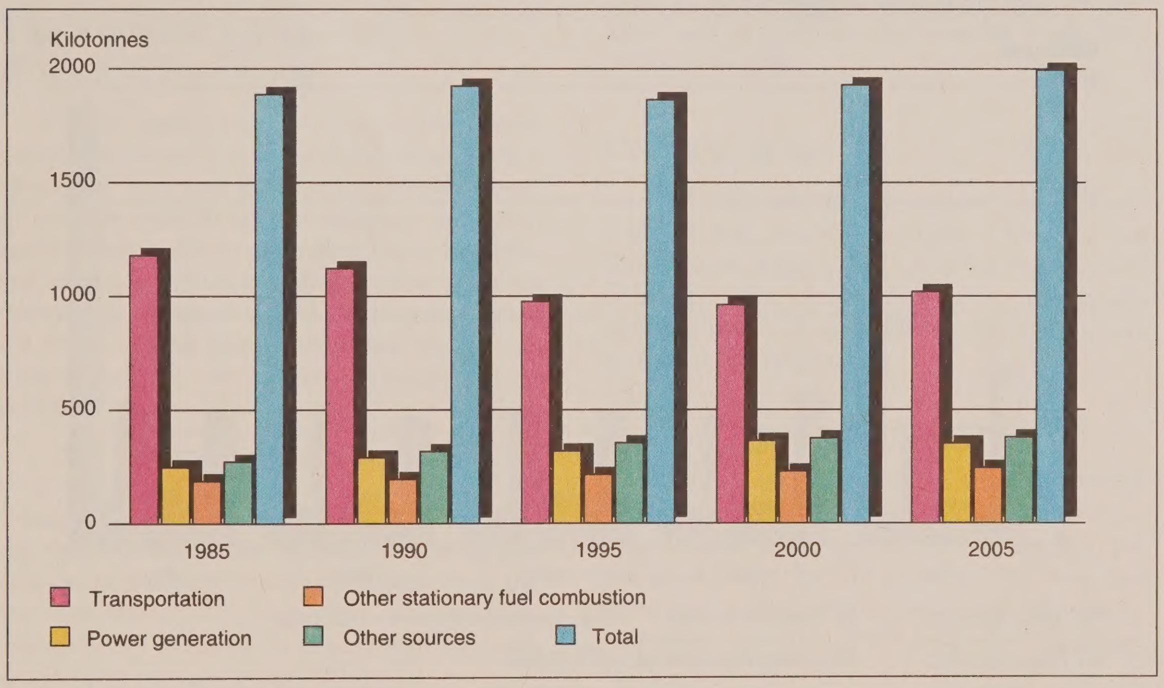
When ozone levels exceed 82 ppb, there is evidence that more people are admitted to hospitals with acute respiratory diseases. Bates and Sizto (1987) reported that high ozone levels coincided with increased admission of patients with acute respiratory disease to 79 hospitals in southern Ontario. However, it is difficult to separate the effects of ozone from those of sulphate in these epidemiological studies. Furthermore, the health effects of individual pollutants may be intensified when two or more pollutants occur together.

Heavy exercise for 2 hours at an exposure of 120 ppb may lead to coughing, shortness of breath, and pain on deep inhalation in healthy adults. Exposures above 120 ppb have resulted in dryness of the throat, shortness of breath, chest tightness and pain, wheezing, fatigue, headaches, and nausea (McDonnell *et al.* 1983, cited in Lippmann 1989).

People working or exercising outdoors inhale larger quantities of air and may suffer more during episodes of ozone pollution. Children are more susceptible because they spend more time outside than adults. Studies by Kinney *et al.* (1988) showed that children at summer camps in Canada

High concentrations of ozone may affect the health of people and vegetation and corrode materials

Figure 2
Estimates of nitrogen oxide emissions due to human activities in Canada during 1985–2005



Source: Adapted from CCME (1990).

and the United States where they were exposed to a typical summer mix of pollutants, including ozone, experienced a measurable decline in lung function.

Ozone causes similar decreases in lung function in people who have asthma as in those who do not, but the loss is more likely to be serious in those whose lungs are already unhealthy. In clinical studies, people with asthma do not respond to ozone differently than any other population. However, there is recent evidence that when asthmatics are exposed to ozone their sensitivity to allergens is heightened (Molfino *et al.* 1991).

Lung function is known to decline with age. Studies of the exposure of human populations to ozone have noted an increase in the rate at which lung function declines. Scientists are researching whether long-term exposure is causing changes in human cells and tissues.

The savings that could be achieved by cutting ground-level ozone pollution are likely considerable

The savings that could be achieved by cutting ground-level ozone pollution are likely considerable but have not yet been estimated for Canada.

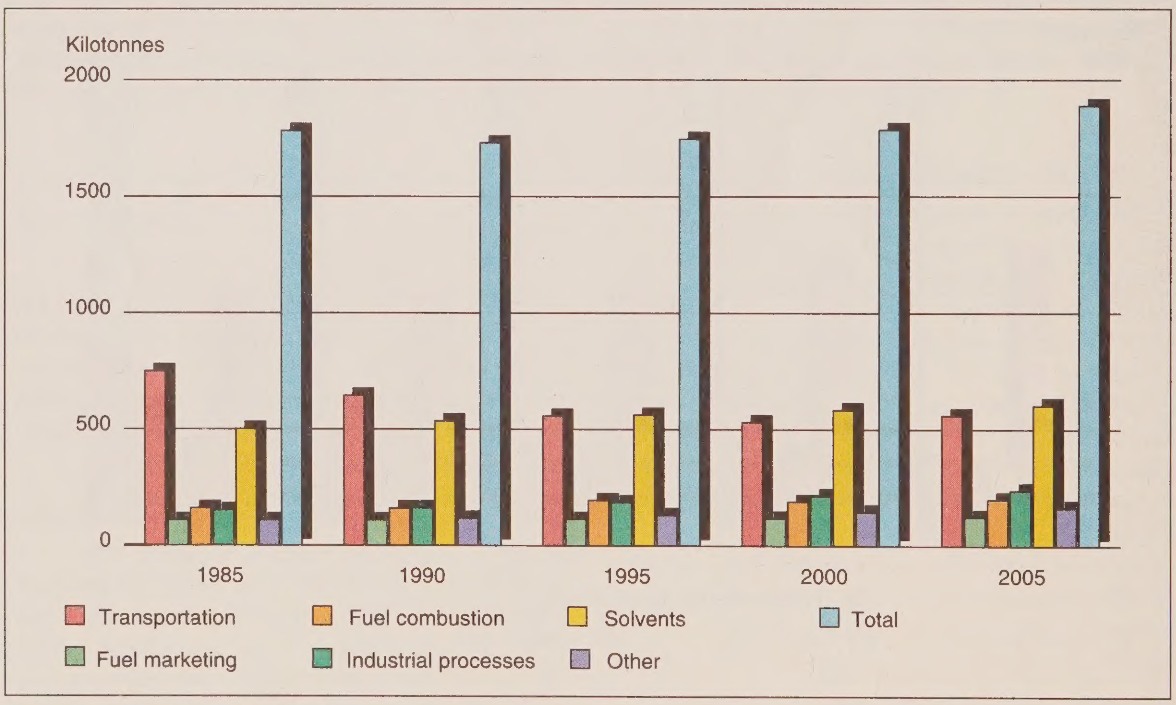
Effects on vegetation

Ozone is now viewed as the most important pollutant affecting vegetation. Canadian research on the impact that ozone is having on farming has focused mainly on southern Ontario, where ozone levels are typically highest. Estimates of the cost of reduced yields in southern Ontario range from $17 to $70 million, depending on the number of ozone events (CCME 1990). Ozone damage to crops also occurs in other regions. Value of lost production in the Fraser Valley has been estimated at $8.8 million annually.

Ozone damages leaf tissue. Leaves may become mottled with yellow, exhibit small black or white spots, develop larger bronze-coloured, paper-thin areas, or exhibit other visible symptoms. Inside the leaf, ozone can inhibit metabolic activity, destroy the walls of cells, damage chlorophyll, and reduce photosynthesis. The plant as a whole may grow 10–40% more slowly, age prematurely, lose its leaves during the growing season, and produce pollen with a shorter life span.

The effects of ozone on ecosystems are difficult to measure, because species vary in their

Figure 3
Estimates of VOC emissions due to human activities in Canada during 1985–2005



Source: Adapted from CCME (1990).

susceptibility. In forest ecosystems, exposure to ozone may lead to increased vulnerability to disease and other stresses, increased mortality of individuals, and eventually to overall decline of affected species (CCME 1990). Both the degree of, and reasons for, the decline in forest health in eastern North America are still debatable, but ozone is believed to be partly responsible for the reported decline of red spruce, sugar maple, and white birch.

Damage to materials

Ozone can lead to the development of cracks in products made of rubber or synthetic rubber, such as tires, boots, gloves, and hoses. Continued exposure to high levels of ozone can cause these products to disintegrate completely. Ozone accelerates the fading of dyes; damages cotton, acetate, nylon, polyester, and other textiles; and accelerates the deterioration of some paints and coatings.

It is difficult to pin down the costs of this type of ozone damage. The economic impact in the United States has been estimated at $1 billion, but a similar estimate has yet to be prepared for Canada.

The Ambient Air Quality Objective for Ozone

An air quality objective is a statement of the concentration of a specified air pollutant that should not be exceeded beyond a specified length of time, in order to provide adequate protection against adverse effects on humans, animals, plants, and materials. Pollution control agencies routinely monitor the levels of air pollutants and compare the levels with air quality objectives. This allows them to measure their progress in controlling air pollution.

The maximum acceptable level for ground-level ozone in Canada is set at 82 ppb over a 1-hour period. An "episode" occurs when the average ozone concentration exceeds 82 ppb for one hour or more. Ozone episodes in Canada typically last from one to a few days. It is considered that natural levels of ozone in unpolluted conditions would range between 15 and 25 ppb.

Air and Waste Management Association

Grape leaf with ozone exposure damage

The federal government has provisionally adopted the number of days per year when ozone concentrations exceed the 1-hour air quality objective as its indicator for ground-level ozone (Environment Canada. Indicators Task Force 1991). The objective of the National Environmental Indicators Project is to develop credible, understandable indicators of environmental conditions. These numbers will help decision-makers to make choices consistent with sustainable development and to evaluate the country's progress towards that goal.

Problem areas

CCME has identified the Lower Fraser Valley in B.C., the Windsor–Quebec Corridor, and the Southern Atlantic Region in the Maritimes as ozone problem areas. There are also localized ozone episodes in other urban and rural regions across Canada (Figure 4).

CCME has identified three ozone problem areas

Lower Fraser Valley

The Lower Fraser Valley area includes the region from Vancouver to Chilliwack (Figure 5) — an area whose climate is strongly influenced by the presence of the Pacific Ocean to the west and mountains to the north and east. The presence of mountains close to the coast means that air masses from the Strait of Georgia (situated between Vancouver Island and mainland British Columbia) rise and are funnelled between mountain ranges.

Figure 4
The number of days per year when Canada's 1-hour Ozone Air Quality Objective (82 ppb) was exceeded. The value for each city is the average of that city's three highest years during 1983–90

Source: CCME (1990).

In the Windsor–Quebec Corridor ozone episodes happen more often and last longer than anywhere else in Canada

Local emissions of nitrogen oxides and VOCs are the main contributors to ground-level ozone formation. In the eastern part of the valley, however, the transport of nitrogen oxides, VOCs, and ground-level ozone from Washington State may also be a factor. At the eastern end of the Burrard Inlet, the maximum 1-hour ozone concentration in any given year averages about 150 ppb, although 1-hour concentrations over 200 ppb have been measured. During an ozone episode, hourly concentrations from 110 to 130 ppb can occur 100 km downwind into the Fraser Valley, far beyond major sources of nitrogen oxide and VOC emissions (Davis et al. 1984 and Concord Scientific Corp. and B.H Levelton and Associates 1989, cited in CCME 1990). Episodes are commonly associated with high inland temperatures, clear skies, and calm weather systems.

In the western section of the Greater Vancouver Regional District and south of Vancouver (e.g., the cities of Richmond and Delta), ozone levels rarely exceed the 82 ppb objective. The variation in ozone levels in the region is partly due to the mountainous topography which causes highly localized weather patterns and to ozone scavenging by local sources of nitrogen oxide.

Windsor–Quebec Corridor

The Windsor–Quebec Corridor encompasses a strip of land about 100 km wide along the north shore of lakes Erie and Ontario and along both sides of the St. Lawrence River to Quebec City. Here ozone episodes happen more often and last longer than anywhere else in Canada.

Northeasterly flowing air masses pick up nitrogen oxides, VOCs, and other pollutants from major U.S. sources along the southern shores of the Great Lakes and farther upwind, and carry them down the corridor. Two large American sources of nitrogen oxides and VOCs, Detroit and Cleveland, are located near the head of the corridor. Under southwesterly winds and along the backside of high pressure systems, high ozone concentrations in the southwestern parts of the corridor are due almost entirely to pollution imported from the United States. As one moves down the corridor to Toronto and beyond, the influence of U.S. sources diminishes gradually.

Between Windsor and Toronto, annual maximum ozone levels are normally about 110–160 ppb over a 1-hour period, with highest maximum recorded levels approaching 190 ppb (Figure 6). The southwestern section of Ontario and regions just north of Lake Erie (Long Point and Simcoe) and east of Lake Huron (Kincardine area) experience the greatest duration of exposure to ground-level ozone concentrations greater than 82 ppb. There is a decline in maximum ozone levels between Toronto and Montreal, with peak levels typically between 90 and 130 ppb.

Peak 1-hour concentrations in and downwind of Montreal rise again to 100–160 ppb, with a maximum recorded hourly value of 180 ppb. Concentrations decrease gradually between Montreal and Quebec City. Hourly ozone levels in Quebec City normally peak between 70 and 110 ppb, although values as high as 160 ppb have been recorded. Generally, the Montreal area and downwind sites record far fewer hours of excess ground-level ozone than southern Ontario (CCME 1990).

The large population in the Windsor–Quebec Corridor (about 12 million people) and the susceptibility of the area to ozone episodes result in the greatest potential for human health problems and crop damage from ozone effects in Canada.

Southern Atlantic Region

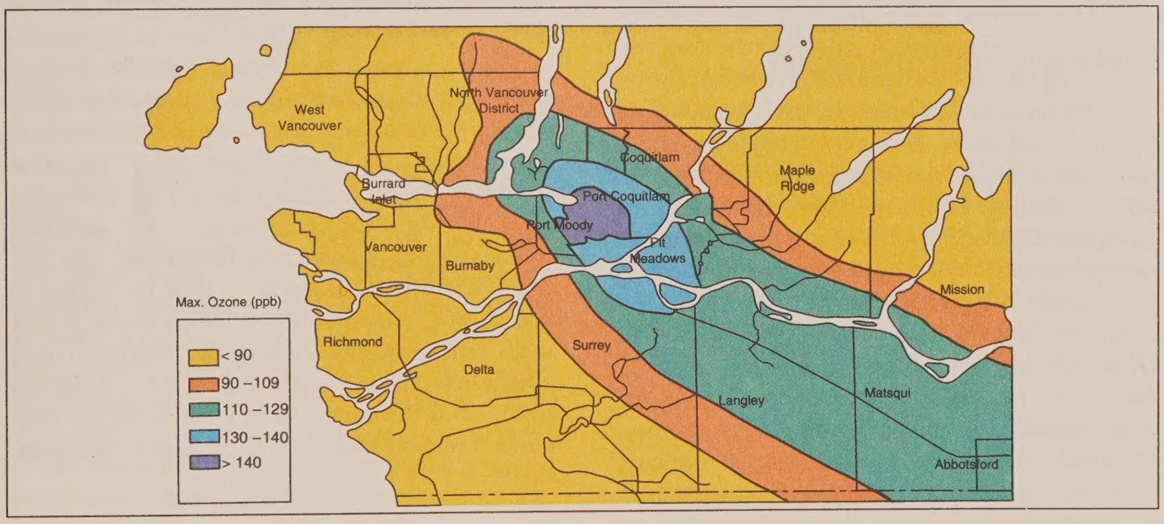
This area surrounds the Bay of Fundy, including southern New Brunswick and western Nova Scotia. Ozone episodes in the Southern Atlantic Region are attributed largely to imported pollutants from the eastern seaboard of the United States. Maximum 1-hour ozone concentrations ranging from 90 to 110 ppb occur most often in southwestern New Brunswick, in central Nova Scotia, and on the south shore of the Bay of Fundy. A peak concentration of 150 ppb was recorded in June 1988 in west-central Nova Scotia, at Kejimkujik National Park. In the Halifax–Dartmouth area, ozone concentrations are normally below 82 ppb.

Other urban and rural environments

Emissions from motor vehicles and industries contribute to the buildup of ground-level ozone in and around urban centres. City size, population density, industrial mix, local meteorology, and geography all influence the extent of ozone formation. Ozone episodes occur in many cities outside the three major problem regions discussed above (Figure 7). Saskatoon and Victoria are the only routinely monitored cities (population over 100 000) where the 1-hour ozone objective of 82 ppb was not exceeded between 1983 and 1990.

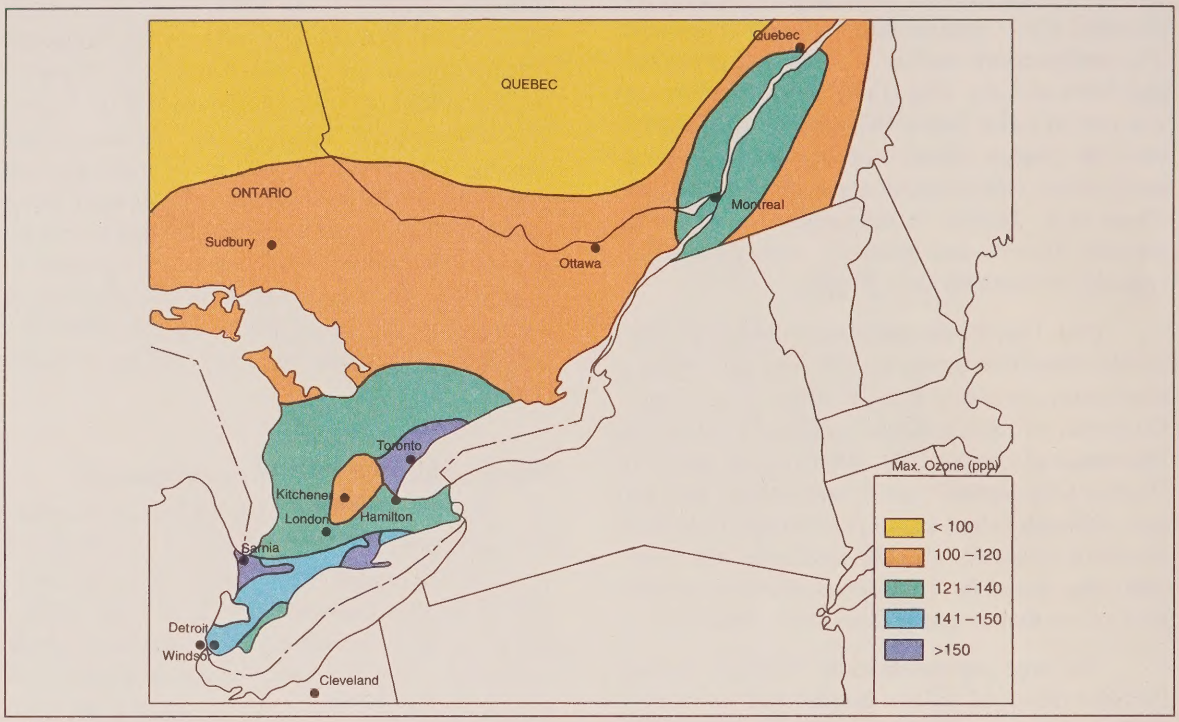
Emissions from motor vehicles and industries contribute to the buildup of ground-level ozone

Figure 5
Maximum 1-hour ozone concentrations in the Vancouver–Chilliwack area, based on an average of the three highest years during 1983–89



Source: CCME (1990).

Figure 6
Maximum 1-hour ozone concentrations in and adjacent to the Windsor–Quebec Corridor, based on an average of the three highest years during 1983–89



Source: CCME (1990).

Prevailing winds and seasonal weather patterns transport ozone and its precursor pollutants hundreds of kilometres from large cities to rural areas. Depending on location, natural background ozone accounts for only an estimated 20–50% of observed rural ozone concentrations.

Emission control options

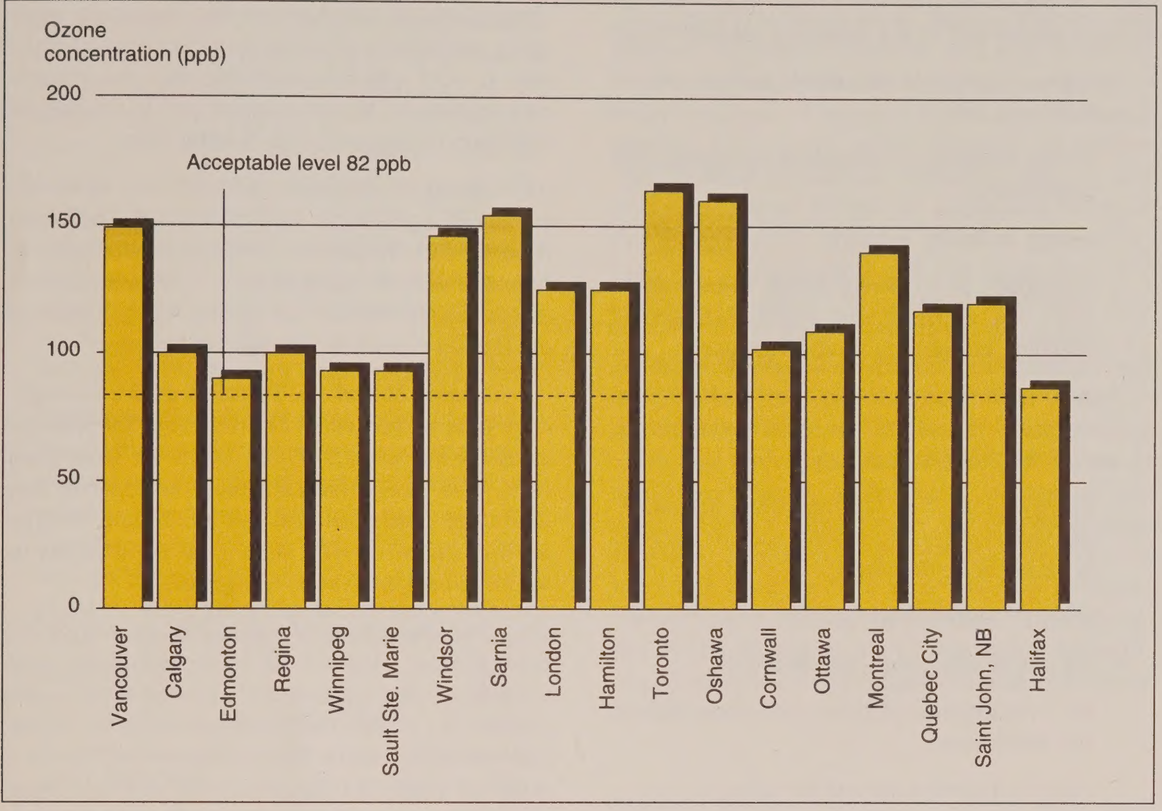
Measures to control ground-level ozone concentrations focus on the reduction of emissions of nitrogen oxides and VOCs

Because ground-level ozone is a secondary pollutant, formed by the reaction of primary pollutants, measures to control ground-level ozone concentrations focus on the reduction of emissions of nitrogen oxides and VOCs. The amount of ozone formed depends on the ratio of nitrogen oxides to VOCs in the atmospheric mixture. Under certain conditions, ozone formation could be limited more effectively by controlling nitrogen oxides more than VOCs, and under other conditions the reverse could be true. The complex nature of the problem has made evaluation of control strategies difficult. Computer models are needed to predict the degree of ozone formation based on particular atmospheric conditions. As warm temperatures and sunlight are needed for ozone formation, it is especially important to reduce summer daytime emissions.

International focus for the control of nitrogen oxides and VOCs

International protocols:—In 1988, Canada and 24 other countries signed a protocol to stabilize emissions of nitrogen oxides at 1987 levels by 1994. Canada, the United States, and 19 European countries signed another protocol in November 1991 to reduce the emission of VOCs and their transport across international boundaries. The protocol commits Canada to a 30% reduction in annual VOC emissions in the Lower Fraser Valley and Windsor–Quebec Corridor by 1999 based upon 1988 levels. Canada is also committed to a national freeze on VOC emissions at 1988 levels by 1999 (United Nations Economic Commission for Europe 1991).

Figure 7
Maximum 1-hour ozone concentrations for Canadian cities, based on an average of the three highest years during 1983–90



Source: CCME (1990).

The Canada–U.S. Air Quality Accord:—In March, 1991, Canada and the United States signed an Air Quality Accord. This agreement addresses the acid rain problem and provides for the study and control of those air pollutants that commonly move across the Canada–U.S. border. Annexes will be developed to specifically address urban smog.

International Joint Commission recommendations on air quality in the Detroit–Windsor–Port Huron–Sarnia Region:—In March 1992, the International Joint Commission (IJC) highlighted the need for governments to phase out emissions of air toxics in the region. Among 19 recommendations, the IJC promoted development of a joint regional ozone control strategy which includes emission controls for mobile and stationary sources, including coke ovens. A common ground-level ozone standard has also been recommended for the region.

Canada's management plan for nitrogen oxides and VOCs

A national plan for the management of nitrogen oxides and VOCs has been developed for the management of nitrogen oxides and VOCs

A national plan for the management of nitrogen oxides and VOCs has been developed by federal and provincial governments through the Canadian Council of Ministers of the Environment (CCME 1990). Initiated in 1988 as a coordinated approach to reducing levels of ground-level ozone throughout the country, the plan was developed in consultation with industry, public interest groups, and environmental groups. It aims for consistent attainment of the 1-hour ground-level ozone air quality objective of 82 ppb by the year 2005. Implementation is occurring in several phases:

Phase I (to be in place by 1995):

a) National Prevention Program: The program outlines 31 initiatives that will reduce emissions of nitrogen oxides and VOCs, including the following:

- *Energy-conservation and product-improvement measures*:
  - energy efficiency standards in equipment and appliances;
  - energy audits by industry;
  - reductions in emissions when surface coatings are applied and when adhesives, sealants, and general solvents are used.
- *Public education to promote informed consumer choice and an environmentally responsible lifestyle including*:
  - energy-conserving driving habits and alternative transportation modes, such as cycling, walking, and ridesharing;
  - energy conservation;
  - the use of energy-efficient products;
  - the construction of energy-efficient homes and businesses;
  - improved solvent use and recycling.
- *Source control initiatives*:
  - new emission standards for cars and light trucks;
  - caps on emissions of nitrogen oxides from trains;
  - emission guidelines for new sources, i.e., power plants, industrial boilers, and compressor engines, as well as for storage tanks for volatile liquids, chemical processes used by industry, commercial and industrial coating applications, printing, degreasing, and dry cleaning.

b) Remedial programs: The plan identifies 27 sample regional initiatives for reducing ozone, which could be implemented in the three ozone problem areas: the Lower Fraser Valley, the Windsor–Quebec Corridor, the Southern Atlantic Region. Most initiatives involve the installation, retrofit, or enhancement of emission-control technologies for existing sources.

c) Study initiatives: The plan outlines 24 research initiatives aimed at determining the most effective control strategies for limiting the formation of ground-level ozone. Ambient air monitoring, modelling and studies of industrial processes and emission sources will help to determine what controls on emissions of nitrogen oxides and VOCs will be necessary in Phases II and III of the plan.

d) Federal–provincial agreements: Federal–provincial agreements will establish the responsibilities of the respective governments for specific remedial actions required to reduce ground-level ozone concentrations. The agreements will also set out interim targets for emission reductions.

Phases II and III: Phase II of the management plan will establish emission caps for problem areas for the years 2000 and 2005. To meet these caps, it is likely that additional steps, over and above the initiatives laid out in Phase I, will be needed. Phase III will make final adjustments to emission caps and control programs.

Implementation of Phase I of the NO_x/VOC management plan should be a significant step towards solving the country's ground-level ozone problem by 2005. Maximum ground-level ozone concentrations should be reduced by 15–35% as a result of predicted Canadian and U.S. emission reductions. In addition, joint Canada–U.S. emission reductions will lead to a 40–60% reduction in the time during which the maximum acceptable ground-level ozone objective (82 ppb) is exceeded in the regions of greatest concern.

Some regional remedial measures already underway

- **The Montreal Urban Community** has passed regulations that require dry cleaning and printing facilities, surface-coating applications, and metal degreasing operations to control emissions. Substantial reductions have been achieved.
- **The B.C. Motor Vehicle Branch** is implementing mandatory vehicle emission testing starting in late 1992 under the **Air Care Program**. As a condition of annual license renewal, all light-duty vehicles in the province's Lower Mainland will be inspected for exhaust emissions and emission-control systems. Those not meeting the standards will undergo repairs.

- In the industrial sector, members of the **Canadian Petroleum Products Institute** have agreed to lower the volatility of gasoline during the summer months in the three ozone problem areas. Gas that is less volatile evaporates less readily, so emissions from service stations and motor vehicles are reduced considerably. Petroleum refiners have voluntarily implemented gasoline vapour recovery at service stations in the Lower Fraser Valley. The largest fuel terminal in Canada, located in Toronto, has also been equipped with a vapour recovery system. Other industrial sectors have initiated studies to measure their emissions and, where necessary, identify ways these could be lowered.
- **Transport Canada** has the mandate to regulate new vehicle emissions. Current car standards, adopted in 1987, should lead to substantial progressive reductions in the total emissions from Canadian cars until the year 2000. In a voluntary gesture, the auto industry has started to phase in more stringent emission controls for 1994, which Transport Canada will make mandatory in 1996.
- The **Regional Municipality of Ottawa–Carleton** and an interagency network known as **GO GREEN** in the B.C. Lower Mainland have initiated educational compaigns aimed at encouraging people to switch from single-occupancy vehicle use to more environmentally friendly means of travel such as walking, cycling, car pooling, and public transit. The **City of Calgary** is initiating a program known as **SMOG FREE** in cooperation with private industry, which will be the world's first voluntary vehicle emissions testing program. The program will provide discount coupons toward automobile repairs performed to reduce vehicle emissions.

Conclusion

Canada has a ground-level ozone problem principally in the Lower Fraser Valley, the Windsor–Quebec Corridor, and the Southern Atlantic Region. If immediate action is not taken to lower emissions of nitrogen oxides and VOCs, the situation will worsen as emissions rise in concert with growing populations, industrial activity, and unchecked use of the private automobile. Without the introduction of new control measures, Canadian nitrogen oxide and VOC emissions will probably be about 6% higher in 2005 than they were in 1985. This would make for serious air quality problems in current areas of concern and would create new problem areas. The effects of ground-level ozone on the health of people and plants are already costing millions of dollars in health care charges, absenteeism, and smaller harvests. CCME's management plan for controlling emission of nitrogen oxides and VOCs outlines the work that must be done to address the problem. The success of the plan depends upon the cooperation of the provinces, the United States, industry, nongovernmental organizations, and individual Canadians.

CCME's management plan for controlling emission of nitrogen oxides and VOCs outlines the work that must be done

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For further information

Supplementary information on the NO_x/VOC management plan may be obtained from the following address:

The NO_x/VOC Office
100 Sparks Street, Suite 360
Ottawa, Ontario
K1P 5B7

Information on State of the Environment Reporting may be obtained from the following address:

State of the Environment Reporting
Environment Canada
Ottawa, Ontario
K1A 0H3

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Canada